MEASUREMENTS OF TEST TIME IN THE GALCIT 17" SHOCK TUBE

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Experimental measurements of test time were obtained in the GALCIT 17" shock tube[1] using both air and argon for driven gases. One series of tests was conducted using a constant driver pressure (pure helium) for various initial pressures of the driven gases. Another series was conducted using air for the driven gas at various initial pressures holding the shock Mach number constant. The data are presented and compared to theoretical predictions computed from the theory in two recent papers by Mirels for the case of a laminar[2] and turbulent[3] wall boundary layer. UNCL. AUTHOR

Test times were obtained at the centerline of the shock tube using two different contact surface probes to detect arrival of the contact surface (in a manner similar to that described in Ref. 4); these were a stagnation-point heat transfer gauge and a cold wire gauge. The stagnation-point heat transfer gauge consisted of a thin platinum film deposited on a one-eighth inch diameter quartz rod. The cold wire probe consisted of a .0005 inch diameter platinum wire; due to its low resistance it was useful at higher Mach numbers for avoiding shorting by the slightly ionized gas (particularly argon). Initially it was felt that the lifetime of the stagnation-point heat transfer gauge would be longer than that of the cold wire, but this

was found not to be the case so the cold wire probe was used to obtain all the data for the series of constant Mach number tests. For the very low initial pressures of the driven gas ($p_1 \leq 100 \, \mu$ Hg) it was possible to measure the shock-wave contact-surface separation distance (and thus test time) from a station a few centimeters from the end wall (x_s = 20.332 meters from the diaphragm). Test times for the higher initial pressures were obtained at a station farther from the end wall (x_s = 16.668 m).

In order to determine the time between shock passage and transition (if any) to a turbulent boundary layer, the response of a thin-film resistance gauge on the side wall was recorded along with the oscillograph recording of the voltage change of the contact surface probe during each test. Transition Reynolds numbers as defined in Refs. 5 and 6 were found to be between two and four million.

The results presented in Figs. 1 and 2 were obtained using helium at a constant driver pressure. Initial pressures, p_1, of the driven gas ranged from 50 μ Hg to 20 mm Hg ($7.12 \geq M_s \geq 2.81$) for air and from 10 μ Hg to 15 mm Hg ($8.18 \geq M_s \geq 3.13$) for argon. The ideal test time was computed for each test condition and appears as the uppermost curve in both Figs. 1 and 2. The theoretically predicted test times were computed using Mirels' laminar[2] and turbulent[3] theories and are presented with the data in Figs. 1 and 2. The fact that the laminar and turbulent theoretical predictions nearly fair into one another in Fig. 2 is an accidental consequence of the particular driver conditions used.

Agreement between the data and theoretical predictions seems to be slightly better for air than argon. For the argon data

($10~\mu$ Hg $\leq p_1 \leq 35~\mu$ Hg) the observed test times are about 30%
greater than the values predicted by the laminar theory, while
for $35~\mu$ Hg $\leq p_1 \leq 1$ mm Hg they are within 10%. At the lower
pressures this discrepancy may be due to the fact that the separation
distance between the shock and contact surface is then of the order
of a tube diameter, and the assumptions of the theory may be some-
what violated. Fig. 2 shows that the observed test time in air is
within 10% of the value predicted by the laminar theory
($50~\mu$ Hg $\leq p_1 \leq 1$ mm Hg). However, in the region where the
turbulent theory is expected to be valid, the observed test times
in air are approximately 10% less than those predicted, and in argon
the test times are 25% greater than those predicted. The systematic
discrepancy between the theory and measurements for argon in the
turbulent case is puzzling when compared with the good agreement
for air.

A constant shock Mach number of 4.23 ($\pm$ 2%) was obtained
for various initial pressures, p_1, of air by using various mixtures
of helium and nitrogen in the driver. The experimental test time
and corresponding theoretical predictions for this series are
presented in Fig. 3. At the low initial pressures the test time
increases rapidly with increasing pressure. When transition to a
turbulent boundary layer begins to occur ahead of the contact
surface, the test time is reduced due to the greater displacement
thickness of the turbulent boundary layer (which allows more mass
to 'leak' past the contact surface). The transition point moves
farther ahead of the contact surface as the pressure is increased.

The effect of the transition moving farther ahead of the contact
surface is to further reduce test time, and for a small range of
pressures (1.5 mm Hg $\lesssim$ p_1 $\lesssim$ 4 mm Hg) this effect is greater than
the increasing effect on the test time due to the increasing
initial pressure, so the test time continues to decrease as the
pressure is raised. Eventually the effect of increasing initial
pressure on test time is greater than the effect of the forward
movement of the transition point, and the test time increases again.
Here also the agreement between theory and experiment is within 10%
where the theory applies.

Mirels stated that the limits of application of the laminar
theory was dp_1 $\lesssim$ .5 and the turbulent theory dp_1 $\gtrsim$ 5 (d = tube
diameter in inches, p_1 = initial pressure cm Hg). Therefore, in
the 17" shock tube we would expect to observe a transition region
from the case where the boundary layer is entirely laminar p_1 $\lesssim$ 300 μ Hg)
to where it is predominantly turbulent p_1 $\gtrsim$ 3 mm Hg). In Figs. 1 and 2
this region is disguised due to the changing Mach number along the curves.
However, from Fig. 3 it appears that the transition region in our shock
tube is somewhat higher in pressure, approximately 1.5 mm Hg $\lesssim$ p_1 $\lesssim$ 5 mm
Hg. The higher transition Reynolds number is probably due to the very
smooth (honed) surface of this stainless steel shock tube.

The laminar theory seems to give a very good estimate of test
time when the boundary layer between the shock and contact surface
is entirely laminar, and the turbulent theory seems to give a reason-
able estimate when the boundary layer is at least 50% turbulent.

ACKNOWLEDGMENT

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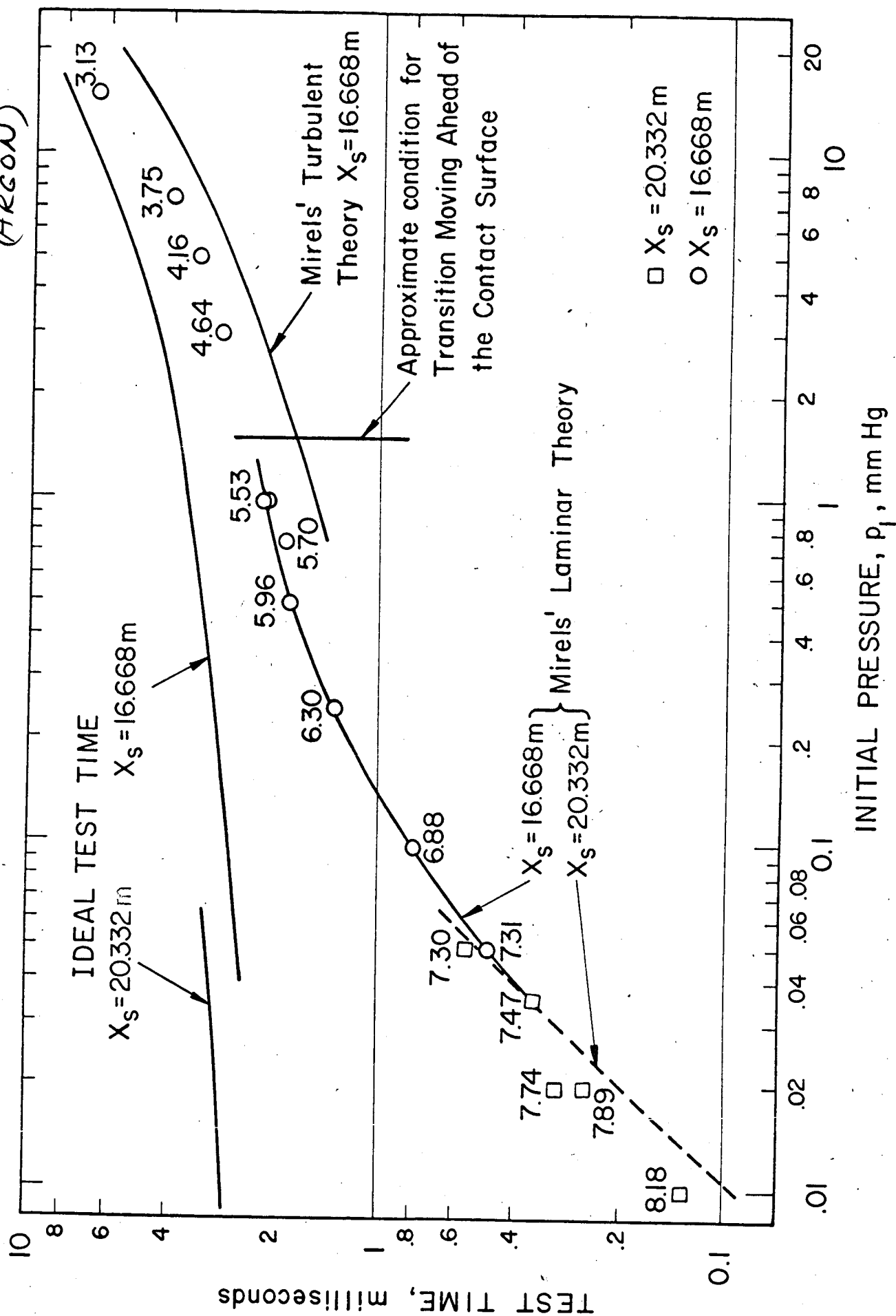
TITLES FOR FIGURES

Fig. 1   TEST TIME VS INITIAL PRESSURE, p_1, CONSTANT DRIVER

SERIES, USING ARGON FOR THE DRIVEN GAS. SHOCK MACH

NUMBER INDICATED FOR EACH EXPERIMENTAL POINT.

Fig. 2   TEST TIME VS INITIAL PRESSURE, p_1, CONSTANT DRIVER

SERIES, USING AIR FOR THE DRIVEN GAS. SHOCK MACH

NUMBER INDICATED FOR EACH EXPERIMENTAL POINT.

Fig. 3   TEST TIME VS INITIAL PRESSURE, p_1, CONSTANT SHOCK

MACH NUMBER SERIES, $M_s = 4.2 \pm .1$, USING AIR FOR THE

DRIVEN GAS.

FIG. 1 (ARGON)

Test time (milliseconds) vs initial pressure, p_1, mm Hg for argon. Data points shown for $X_s = 20.332$ m (squares) and $X_s = 16.668$ m (circles), compared with Mirels' Turbulent Theory, Mirels' Laminar Theory, ideal test time curves, and approximate condition for transition moving ahead of the contact surface.
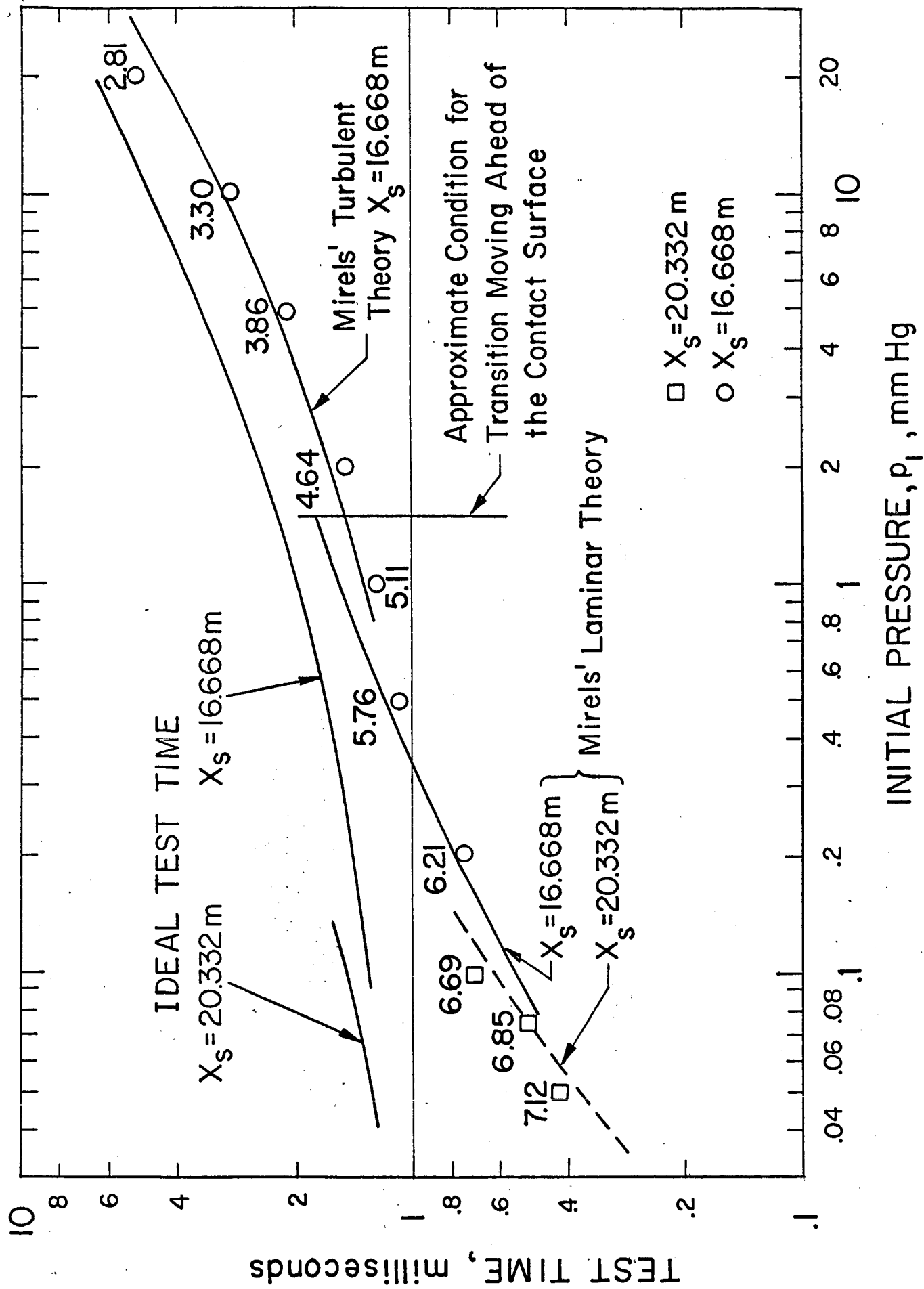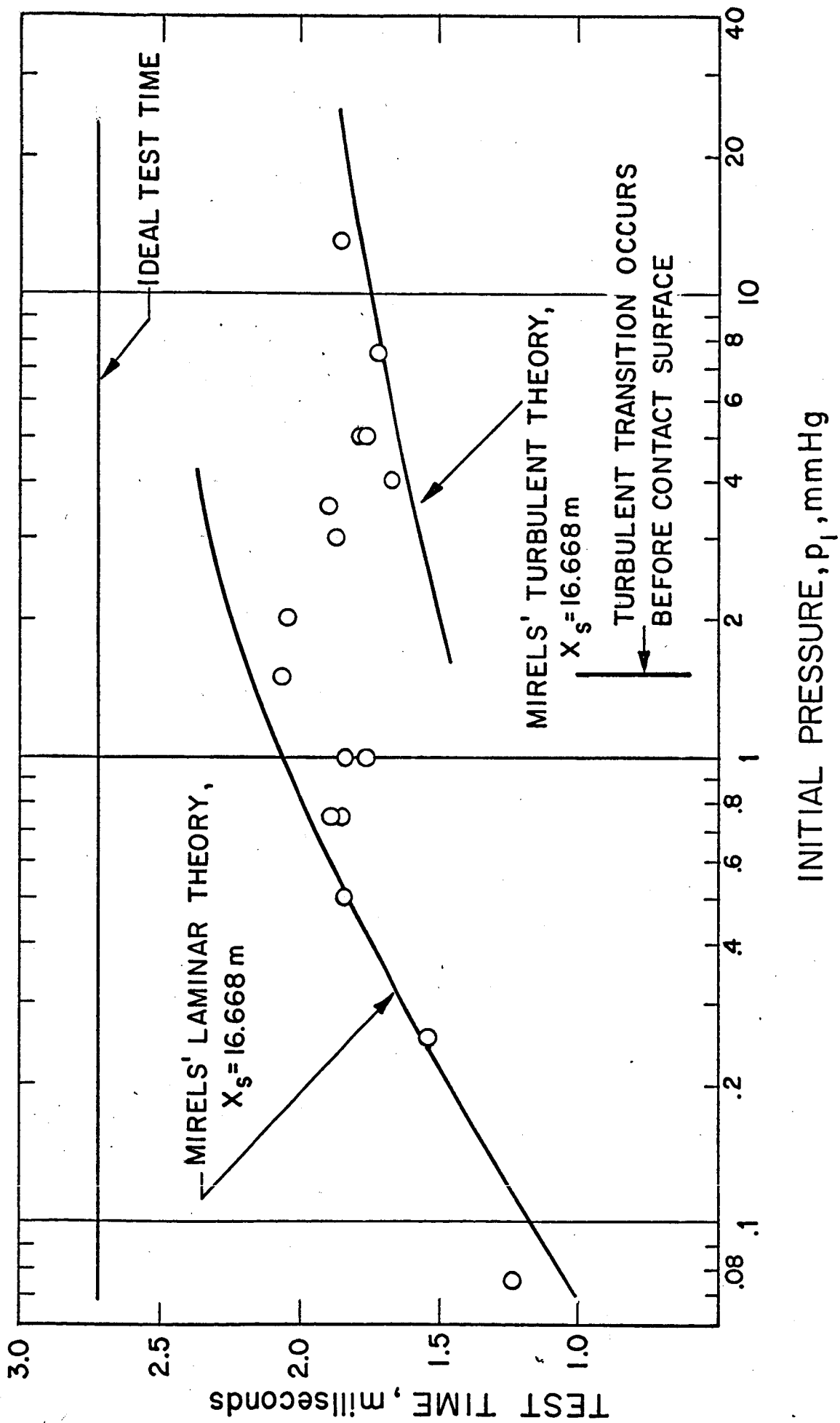
FIG. 2 (AIR)

Fig. 3
$M_s = 4.23$
(AIR)

Figure axes: TEST TIME, milliseconds (vertical); INITIAL PRESSURE, p_1, mmHg (horizontal)

IDEAL TEST TIME

MIRELS' TURBULENT THEORY, $X_s = 16.668$ m

TURBULENT TRANSITION OCCURS BEFORE CONTACT SURFACE

MIRELS' LAMINAR THEORY, $X_s = 16.668$ m